LIGHTING DATA

EDISON LAMP WORKS
OF GENERAL ELECTRIC COMPANY

GENERAL SALES OFFICE HARRISON, N. J.

Edison MAZDA Lamps Theory and Characteristics

Information compiled by
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Commercial Engineering Department

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SYNOPSIS: PAGE

For information regarding MAZDA lamps and lighting questions, refer to the nearest sales office as listed on the last page of this bulletin.

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Introductory

Any illuminant to be successful, should have certain characteristics in brief as follows:

High efficiency
Simplicity of maintenance
Adaptability to reflecting and diffusing devices
A wide range of sizes
Steadiness of light
Reliability of service
Good maintenance of candle-power
Low investment cost

The MAZDA lamp fulfilling these requirements to the greatest degree of any commercial electric illuminant, has become practically the standard. It meets the above outlined demands as to service in a thoroughly satisfactory manner. By far the greater proportion of electric lighting is accomplished by incandescent lamps.

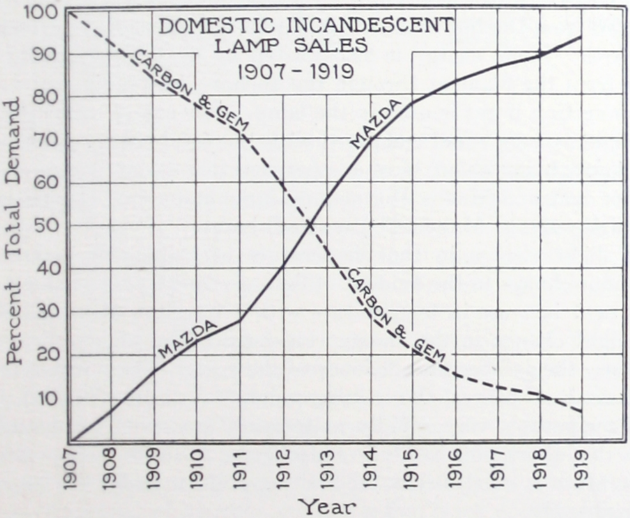


FIG. 1

Diagram Showing Domestic Incandescent Lamp Sales from 1907 to 1919 Inclusive. It is interesting to note the rapid rise of the MAZDA lamp to a position of almost universal application

While the Mazda lamp was introduced only a comparatively few years ago, its excellent characteristics have caused it to replace other forms of incandescent lamps and forge rapidly to the foreground. It is interesting to note Fig. 1, obtained from the report of the Lamp Committee of the National Electric Light Association, which shows the domestic incandescent lamp sales, year by year, for the various types. This indicates in a very clear and graphic manner, how the Mazda lamp has become the standard illuminant.

For 1919, the total sales of incandescent lamps, excluding miniature, amounted to 183,000,000 for domestic use; 170,000,000 of these were of the tungsten filament type. This represents 93 per cent of the total. The carbon lamp is only recommended and properly used under conditions where extremely severe handling and rough usage prevails.

The Filament

The light given by an incandescent lamp is obtained by the passage of electric current through the filament, which heats it to a high temperature and causes it to emit light. Most of the electrical energy (watts) consumed by a lamp is wasted by heat being radiated from the hot filament similar to the sun radiating heat to the earth. Some energy is also wasted by heat being conducted away from the filament through the anchors, leading-in wires and by convection if gas is used in the lamp. The energy transformed into light is very small compared with the total energy consumed by a lamp, being about ½ of one per cent in a carbon lamp, about 1½ per cent in a Mazda B (vacuum) lamp and about 2½ per cent in a high wattage Mazda C (gas-filled) lamp.

A slight change in the temperature of a filament makes an enormous change in the amount of light given (11 per cent for each 1 per cent increase in temperature with a tungsten filament) with but slight change in the energy consumed. The higher the temperature, the greater the efficiency of the lamp. The limiting temperature is, of course, the melting point, but as the filament material evaporates very rapidly at temperatures even considerably below this, shortening its life and blackening the bulb, the operating temperature is much below the melting point in order to obtain a reasonable life.

The only materials now used for filaments are carbon and tungsten. Tungsten, at present used in the Mazda lamp, while having a much lower melting temperature than carbon, can be

operated at a much higher temperature than the carbon filament, as the temperature at which rapid evaporation of tungsten begins is much higher than that for carbon.

For a given rate of evaporation, the temperature at which a carbon filament can be operated depends upon the form of the carbon. 110-volt filaments which are "treated" to give them a graphitic coating can stand a higher temperature than 220-volt filaments which are so small in diameter that they cannot be given this coating. A tungsten filament can operate under gas pressure at a higher temperature than in a vacuum, as the slight pressure of the gas retards the evaporation in the same manner as the boiling point of water is raised above 212 deg. F. in a boiler under steam pressure.

The approximate melting temperatures of carbon and tungsten and operating temperatures of certain lamps are given in the table below.

Lamp Filament		Approx. Operating Temperature	Approx. Melting Temperature
Carbon	60 watts, 220 volts (untreated)	1870 deg. C.	4000 deg. C.
	50 watts, 110 volts (treated)	1930 deg. C.	
Tungsten	25 watts, 110 volts (vacuum)	2150 deg. C.	3300 deg. C.
	500 watts, 110 volts (gas-filled)	2500 deg. C.	
	30 volts, 30 amperes (gas-filled)*	3000 deg. C.	

* Motion picture lamp.

Tungsten

Tungsten is a metal, discovered in 1781, and is an element. It is one of the heaviest metals known, its specific gravity being between 19 and 20, depending upon how much the metal has been worked. It is heavier than lead and about the same weight as gold. The word "tungsten" is derived from the Swedish "Tung" (heavy) and "Sten" (stone). The chemical symbol is "W" (Wolfram).

Tungsten is obtained from various ores, such as Wolframite, which is a tungstate of iron and manganese, and Scheelite, which is a calcium tungstate. Ores are mined in Colorado, California, New Mexico and in many other places. The ore is usually reduced to the oxide, which is a yellow powder resembling sulphur. Other oxides are bluish or brown. Oxides of tungsten are reduced to pure tungsten, which then appears a fine black powder resembling lamp black. Before its use as a filament material, tungsten was used principally for hardening steel.

For many years it was impossible to produce tungsten in the ductile state. Filaments were made by mixing the tungsten powder with a binder squirting the resultant paste through diamond dies, and then reducing the thread thus formed to pure tungsten by burning out the binder.

The ability to draw tungsten into a wire was discovered by the engineers at the Research Laboratories of the General Electric Company at Schenectady. The wire is made by placing pure tungsten powder in a metal mould, and compressing it into a slug by hydraulic pressure, until the particles stick together sufficiently for careful handling. Electric current is then passed through the slug, heating it to almost the melting point, thereby sintering the particles together. The billet thus formed is heated and passed through swaging machines, which hammer it on all sides, reducing its diameter, increasing its length and further compressing the particles. This is repeated until it is about the diameter of the lead in a pencil, so that it then becomes possible to draw it hot through diamond dies. Repeated drawing through smaller and smaller dies results in a ductile tungsten wire having a high tensile strength (from five to six hundred thousand pounds to the square inch). The smaller dies have such a small hole in them that it is impossible to see through them with the unaided eye.

Size of Filament

The amperes flowing through a filament and the temperature at which it is to operate are dependent upon its diameter. A tungsten filament of large diameter can be operated at a higher temperature than one of smaller diameter, as a greater amount of filament material can evaporate without reducing its diameter to as great an extent, and, as previously stated, a filament can be operated under gas pressure at a higher temperature than in a vacuum.

A lamp to consume a given wattage at a given voltage must, of course, have a filament of definite resistance. The resistance of tungsten depends upon its temperature, the higher the temperature the greater its resistance. Anchors and leading-in wires conduct heat away, cooling and therefore reducing the resistance of the filament at these points. If gas is used in the lamp, it also takes heat from the filament, tending to reduce its resistance, which is compensated for by increasing the current density, that is, using a smaller diameter filament.

It will be seen, therefore, that there are many factors which determine the diameter and length of a filament in each lamp. The approximate filament dimensions of a few lamps are given in the table below.

Lamp	Length of Filament	Diameter of Filament
Carbon—50 watts, 110 volts	9 in.	4.00 thousandths of an inch
Mazda B—25 watts, 110 volts	18¼ in.	1.16 thousandths of an inch
Mazda B—50 watts, 110 volts	22 in.	1.82 thousandths of an inch
Mazda B—50 watts, 220 volts	37 in.	1.18 thousandths of an inch
Mazda C—500 watts, 110 volts	34¾ in.	7.92 thousandths of an inch
Mazda C—30 volts, 30 amperes*	11½ in.	24.50 thousandths of an inch

* Motion picture lamp.

In order to appreciate the smallness of the diameter of these filaments, a human hair is about three thousandths of an inch in thickness.

The Vacuum

If the bulb were not exhausted, the oxygen of the air in the bulb would combine with the hot tungsten filament and it would immediately burn out. By exhausting the air, not only is this prevented, but the filament tends to stay hot, requiring less energy to keep it at its operating temperature. This is similar to the vacuum bottle which tends to keep its contents hot, as the heat losses by convection are a minimum.

The Use of Gas

By deliberately inserting an inert gas in the lamp which will not chemically combine with the filament, the slight pressure (about that of the atmosphere) the gas exerts on the filament retards its evaporation as previously explained, so that the filament can be operated at a higher temperature than in a vacuum. However, the use of gas increases the heat lost by convection, so that the gas used should have as poor a heat conductivity as possible. Nitrogen is at present used in the larger sizes of lamps and argon in the smaller sizes.

In order to further reduce the heat losses, the filament is coiled so as to present a small surface to the gas circulating in the bulb. The opposite effect is found in an automobile radiator which has as large a surface as possible so that it may be cooled by the air blowing on it.

The smaller the diameter of the filament, the greater is its surface compared with its volume, so that with a small filament the

heat losses produced by the circulating gas are relatively greater than with a thick filament. There is a point, therefore, where the advantage of the higher temperature of the filament allowed by the use of gas is offset by the relatively greater heat losses with the small filament; below this point a filament in a vacuum will be more efficient. The smallest Mazda C lamp for 110 volts at present made is the 50-watt size, as below this size at present a Mazda B lamp is more efficient.

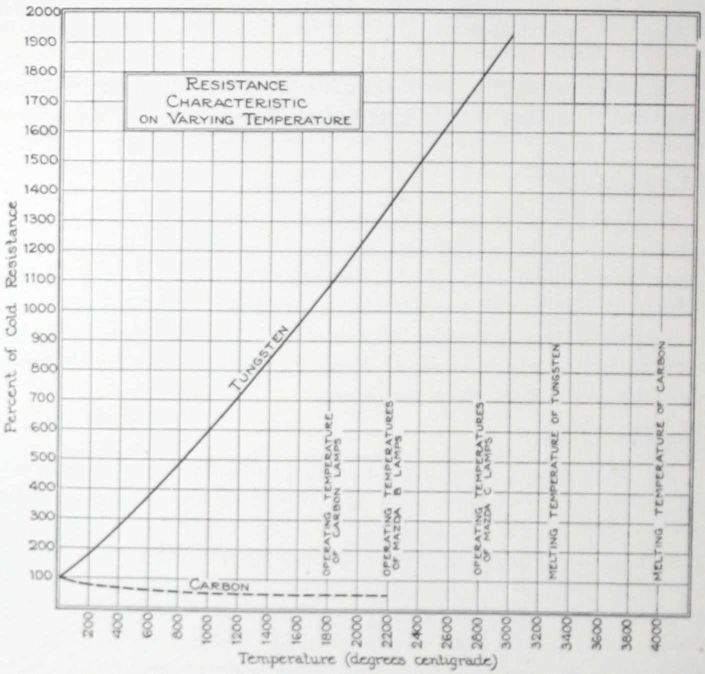


Fig. 2
Resistance Characteristic of Tungsten and Carbon Filaments with Varying Temperature Expressed in Degrees Centigrade

The Resistance Characteristic

As previously stated the electrical resistance (ohms) of tungsten increases with the temperature to a very marked extent, having what is known as a positive temperature coefficient. The resistance of a Mazda B lamp while burning is about 12½ times, and

of a high wattage Mazda C lamp about 14½ times that when unlighted. A carbon filament has a negative temperature coefficient; that is, its resistance while burning is less, being about half that when unlighted. This is illustrated in Fig. 2.

The resistance characteristic on varying voltage is illustrated in Fig. 3. This shows that within ten per cent above and below normal voltage the resistance of the carbon filament is almost constant, dropping but slightly with increasing voltage. The

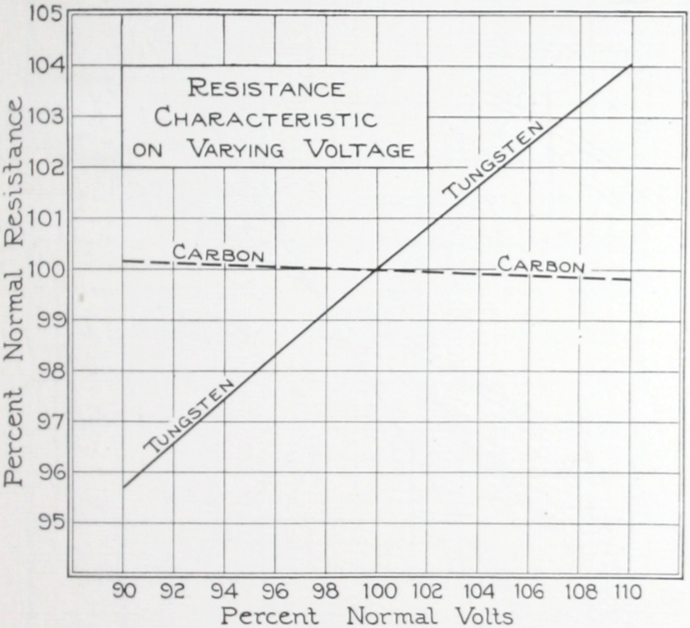


Fig. 3
Resistance Characteristic of Carbon and Tungsten Filaments Expressed in Percentage of Normal Resistance with Voltage Varying Above and Below 100 Per Cent

resistance of the tungsten filament shows a marked increase with increasing voltage.

Ampere and Wattage Characteristics

The tungsten resistance characteristic is in its favor as the change in amperes and therefore watts is not as great as that of a carbon filament on varying voltage as is shown in Fig. 4.

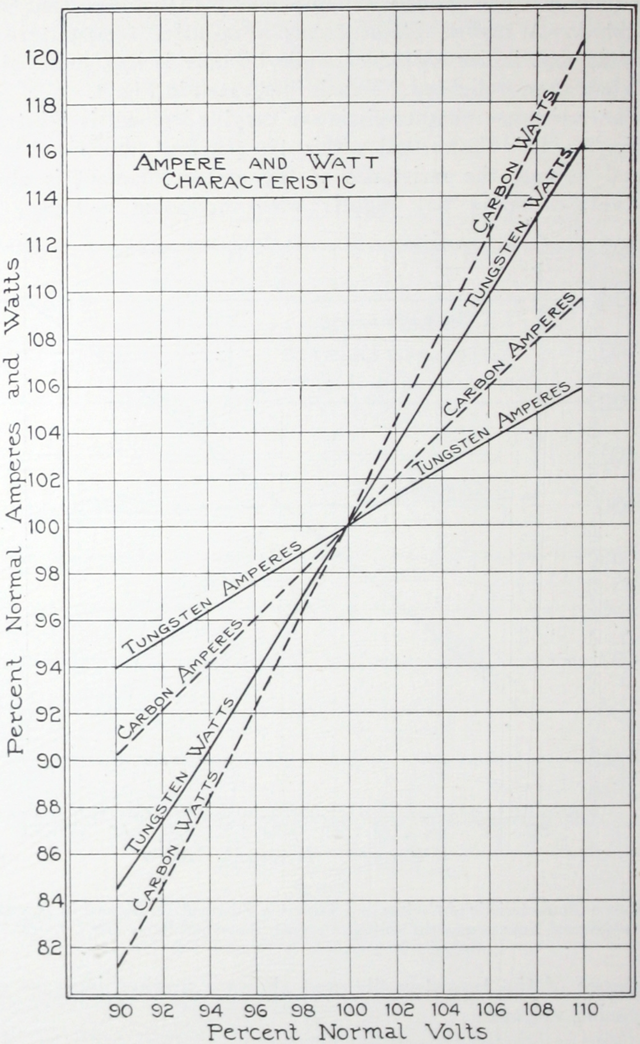


FIG. 4

Curve Showing the Variation in Amperes and Watts for Carbon and Tungsten Filaments with Varying Voltage

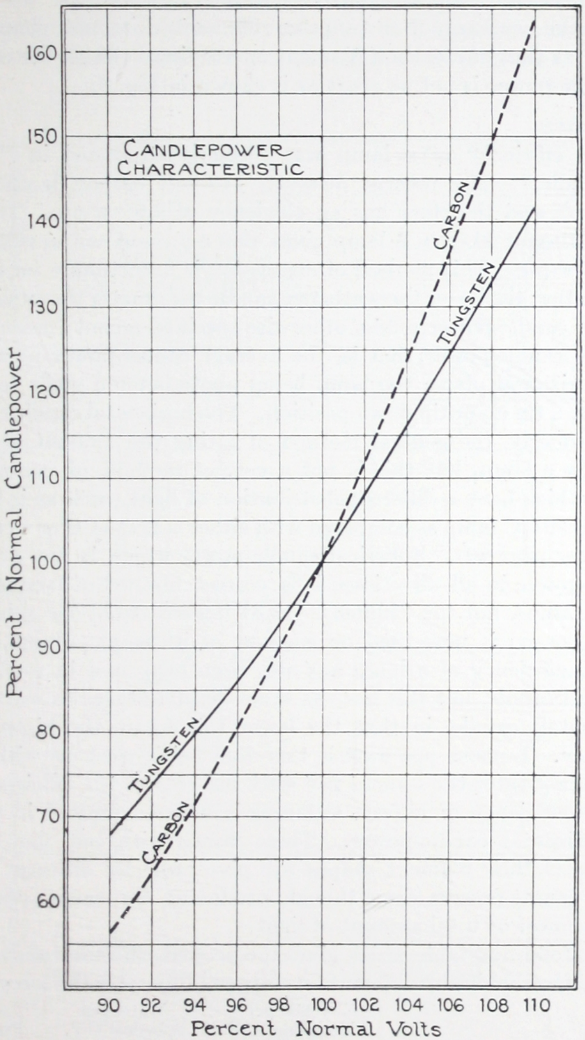


FIG. 5
Variation of Candle-power of Carbon and Tungsten Filaments with Variation of Voltage Above and Below Normal

Candle-power Characteristic

As the wattage of a tungsten filament does not change as greatly as that of a carbon filament on varying voltage, the change in candle-power is not as great as is shown in Fig. 5.

Efficiency

The efficiency of a lamp was formerly expressed in "watts per candle." The present 50-watt, 110-volt carbon lamp gives 16.8 c-p., and therefore has an efficiency of 2.97 w-p-c. The 50-watt, 110-volt MAZDA B lamp gives 49.0 c-p., and has an efficiency of 1.02 w-p-c. This method of expression is unfortunate for it will be seen that the lesser the watts per candle the greater the efficiency.

The candle-power unless otherwise specified meant "mean horizontal" candle-power; that is, the average candle-power measured in a horizontal plane, the lamp being photometered while rotated in either a tip up or tip down position. The horizontal candle-power was formerly the general method of rating the amount of light given by a lamp, but this is not a correct method of comparing lamps which have a different distribution of light, such as is found in a MAZDA C lamp as compared with either a MAZDA B or a carbon lamp (see page 20). Spherical candle-power which is the average candle-power in all directions, is a correct method of comparison of two lamps, but the "lumen" (12.57 lumens equal one spherical candle-power) is now used on account of its many advantages.

The efficiency of a lamp has also been expressed in watts per spherical candle, but this has the same disadvantages as watts per (horizontal) candle, in that the lower this figure the higher the efficiency. Lumens per watt is therefore being used, as with this term, the greater the lumens per watt the greater the efficiency.

The efficiency of MAZDA C lamps is never expressed in watts per horizontal candle-power. These lamps with but slight differences in their filament shapes will give radically different horizontal candle-powers even though producing the same spherical candle-power or total amount of light.

The following table which gives the present efficiency of various lamps expressed in the different terms used, illustrates the foregoing:

Lamp	Watts per Horizontal C-P.	Watts per Spherical C-P.	Lumens Per Watt
Carbon—60 watts, 220 volts	3.69	4.42	2.85
Carbon—50 watts, 110 volts	2.97	3.60	3.30
MAZDA B—50 watts, 110 volts	1.02	1.31	9.59
MAZDA C—75 watts, 110 volts	....	1.09	11.53
MAZDA C—500 watts, 110 volts	....	0.72	17.45
MAZDA C—30 volts, 30 amperes*	....	0.46	27.4

* Motion picture lamp.

As the wattage and candle-power of a tungsten filament does not change as greatly as that of a carbon filament on varying voltage the change in efficiency is not as great, as is shown in Fig. 6.

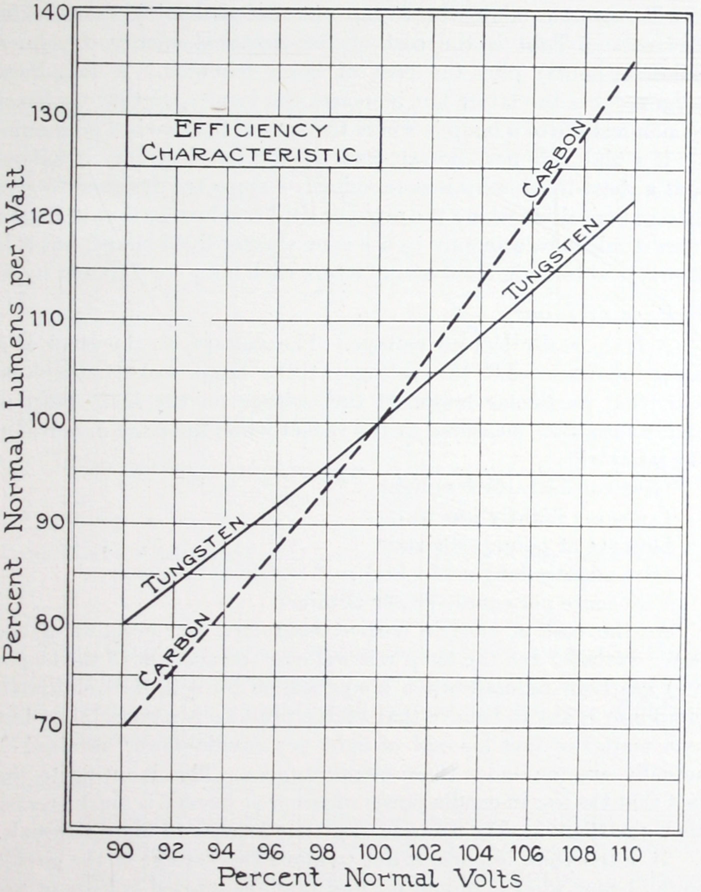


FIG. 6
Variation of Efficiency of Carbon and Tungsten Lamps with Varying Voltage

Economical Life of Lamp

The life of a lamp can be made anything wanted, as the filament can be designed to operate at any temperature desired. A long-lived lamp must operate at a low temperature and is therefore very inefficient; that is, in order to produce a given candle-power, it will consume more watts than one designed for a shorter life. The cost of light is the cost of the electrical energy consumed (kilowatt-hours) plus the cost of lamp renewals. A long-lived lamp reduces the latter but increases the former, so that the most economical life of a lamp is where the sum of the two is a minimum.

If a high rate per kilowatt-hour is paid for electricity it follows that a short-lived lamp is economical. Lamps are designed to give an economical life where the rate per kw-hr. is low, so that at higher rates it might be economy to use even shorter-lived lamps, but it is impractical to design and manufacture each lamp for different lives.

Voltage of Lamp

A lamp really has no voltage. The voltage on the label of a lamp indicates what the voltage at the lamp socket should be with that particular lamp. If the voltage on the lamp label is higher than that measured at the socket while the lamp is burning, the lamp will:

Give considerably less light
Consume slightly less watts
Operate at poorer efficiency
Give slightly longer life, and
Cost more per candle-power obtained

As the cost of electric current consumed (on account of the lesser wattage) and the lamp renewal cost (on account of the longer life) are both reduced when lamps are so burned, the uninitiated lamp user is apt to believe that such a practice is a good thing, but as a matter of fact his cost of light per candle-power obtained is actually greater under these circumstances. This is owing to the fact that the loss in candle-power of lamps so burned is much greater than the slight saving made in electric current and lamp renewals.

It is therefore important not to allow the voltage of the circuit to fall below what it should be, and that the labeled voltage of the lamps used should be no higher than that of the circuit.

Variation in Life of Lamps

In the present state of the art, it is not possible to manufacture every lamp that will give exactly the life for which it is de-

signed, but a large number of lamps will very closely average the designed life. Given a hundred lamps, a few will fail very soon, some will last somewhat longer, some will give about their rated life and the remainder will give lives considerably longer than rated, but the average of the hundred lamps will be close to the rated life. This is illustrated in Fig. 7 which shows the number of lamps of an original lot remaining at each moment throughout the test.

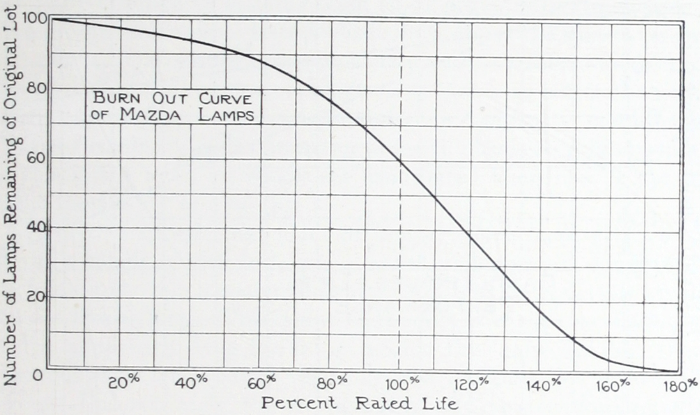


FIG. 7
Curve Showing Results of a Typical Test on a Number of MAZDA Lamps Indicating Number of Lamps Still Burning at Various Percentages of Rated Average Life

From the above curve it will be seen that 60 per cent of the lot of lamps gave lives in excess of their rating and by computing the area covered by the curve the average of the lot was slightly in excess of their rating.

Candle-power Maintenance

As previously stated, the filament material evaporates during the life of a lamp and this deposits on the inside of the bulb, blackening it and thereby cutting down the candle-power. Chemicals known as "Getters" are sometimes put in a lamp to either combine with the evaporated particles and change them into a translucent material or to partially redeposit the particles on the filament. These chemicals therefore tend to maintain the candle-power of a lamp during its life.

The evaporation of the filament during the life of the lamp, in addition to blackening the bulb and so reducing the candle-power of the lamp, also reduces the diameter of the filament. This increases the resistance of the filament, reducing the watts consumed by the lamp and so lowers the temperature at which the filament operates, which further reduces the candle-power.

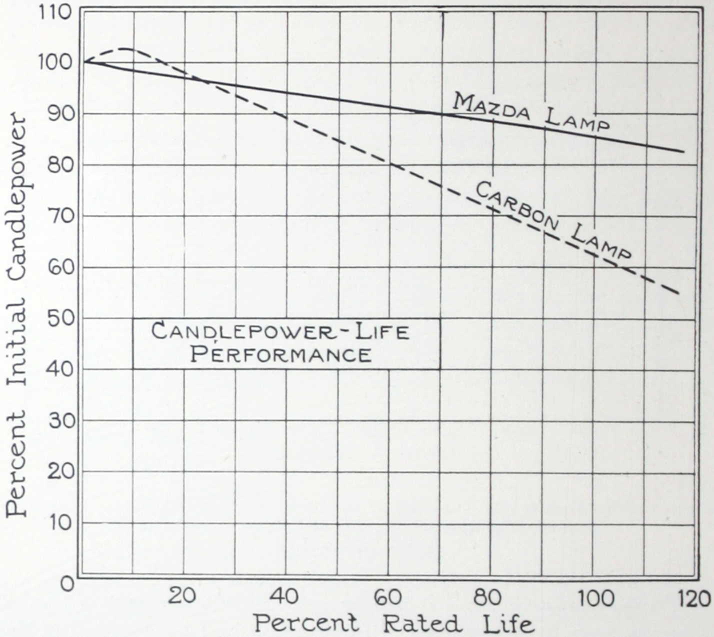


FIG. 8
Curve Showing the Variation in Candle-power During the Life of Carbon and MAZDA Lamps

The average candle-power performance of lamps is shown in Fig. 8. It will be seen that the MAZDA lamp maintains its candle-power much better than the carbon lamp.

Life and Candle-power Performance Tests

The life of a lamp largely depends on the efficiency at which it operates. It is impossible at present to manufacture every lamp to a very exact predetermined efficiency for a given voltage. To obtain reasonably accurate data, it is necessary to carefully photo-

meter each lamp to be tested, in order to determine the actual voltage at which each lamp should be operated so that it will be burning exactly at its rated efficiency. This means measuring each lamp to a fraction of a volt, and then burning the lamps at these various fractional voltages. Furthermore, the voltage should not be allowed to vary more than one quarter of one per cent above or below the normal. Such circuits are impossible without special regulating devices.

It will thus be seen that the true quality of a lot of lamps cannot be determined by burning them on an ordinary lighting circuit. Two groups of lamps so tested which show about the same average life, might, if accurately tested as previously outlined, show that the quality of one lot was as much as 50 per cent better than the other. Quite frequently some manufacturer will play safe on the designed efficiency of his lamps in order to obtain long life results, as this is the basis on which the uninitiated lamp user is apt to judge the quality of a lamp.

It often happens that a lot of lamps, which have given long life in a rough service test, when tested under proper conditions, are found to be much poorer than other lamps in the same test which did not live as long. This is due to the fact that the manufacturer of the apparently long life lamp labeled the lamps so that they operated at a much lower efficiency and are thus low in candle-power. Unfortunately, the eye cannot readily measure considerable differences in the candle-power of lamps without the aid of a photometer.

It is necessary to test a large number of lamps in order to get the true average for any given size of lamp as is shown by a study of Fig. 7. For example, a life test of five lamps might show an average of anywhere between 15 per cent and 165 per cent of the actual average life of a lot of 100 lamps. The cost of only the electric current consumed to make a proper life test on all the usual sizes of lamps used by a consumer who buys about a thousand dollars worth of lamps per year would be about $400. It is therefore impractical for the ordinary lamp user to make life tests that are of any real value.

Standard Voltages

Tungsten wire can be made to very exact diameters and the resistance per unit length is accurately known. This makes it possible to more accurately predetermine the voltage of a MAZDA

lamp than of a carbon lamp. In the 110- to 125-volt range about 50 per cent of a lot of carbon lamps manufactured can be predetermined within one volt, the balance spreading out as much as five volts on either side of the predetermined figure. This resulted in the various lighting companies many years ago adjusting the voltage of their circuits so that lamps of other than 110 volts could be properly used.

Mazda lamps can practically all be manufactured to within one volt of their predetermined voltage, so that with the passing out of the carbon lamp, there is now no longer need to havedifferent voltage circuits. It has therefore been suggested that electric plants raise their voltage to one of the three standards adopted, 110, 115 and 120 volts, which enables the manufacturer to give his customers better service by having to carry only three, instead of as in the past, 30 different voltage lamps in stock. In 1913, when this scheme was first suggested, about one third of all lamps sold were of the three standard voltages. Over four fifths of all lamps now manufactured are of the standard voltages.

Finish of Bulb

Where lamps are used so that the bright filament is likely to come in the angle of view it is necessary to provide some means of diffusing the light. Frosted lamps are serviceable in this connection.

Where lamps are used in open bottom reflectors, the lower portion of the bulb is frosted, which is known as bowl frosting. Certain types of lamps, such as round bulb, and lamps used bare, should be all frosted.

A finish known as bowl enamel has been recently developed and is applied to Mazda C lamps. This is obtained by spraying the lower part of the lamp bulb with a white mineral material in a suitable solution. It results in a smooth finish, dull white in color, which gives excellent diffusion and has considerably lower brightness than the bowl frosted lamp.

Bowl Enameling as applied to Mazda lamps will not chip, crack nor discolor and is not subject to depreciation on being exposed to acid fumes. It can be washed without damaging the enamel and cleaning is a very simple proposition. It has a special advantage over bowl frosting, in that dirt and foreign material collecting on the white surface is more readily visible than when on the etched surface of the bowl frosted lamp and the lamp is more likely to

be cleaned. There are a number of other advantages of bowl enameling of which space will not permit a discussion.

Diffusing bulb lamps are not receiving as wide use as desirable. This condition is due to the impression that they absorb a high percentage of the light. This is not the case as indicated by the table given below. The gain in ability to see far more than offsets any loss of light produced.

	Total Lumens
Clear lamp	100 %
Bowl frosted	97.5%
Bowl enameled	92 %
All frosted	92 %

Assuming the total output of a clear lamp in a translucent reflector to be 100 per cent; if this lamp were bowl frosted, the output would be about 97.5 per cent, and if bowl enameled about 88 per cent. The downward lumens of this combination would be decreased slightly. If the downward lumens of the clear lamp and reflector were 100 per cent, a bowl frosted lamp in the same reflector would give about 94 per cent of this value and a bowl enameled lamp about 79 per cent.

If the downward lumens of a clear lamp in an opaque RLM Standard dome reflector were 100 per cent, this would be reduced to approximately 92 per cent by substituting a bowl frosted lamp, and to approximately 82 per cent by substituting a bowl enameled lamp.

Distribution of Light as Affected by the Shape of Filament

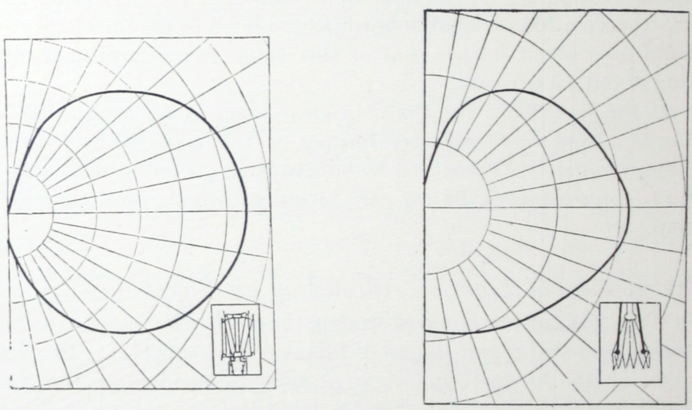
With the introduction of drawn tungsten wire as the incandescent material many shapes of filament have resulted. This has been due to the fact that it is possible to manipulate the wire readily and cause the light source to be of almost any desired shape. Naturally, extreme variation in the contour of the luminous body will cause a change in the distribution of light.

Data on the candle-power distribution curve of the bare lamp are of interest to the designer of lighting auxiliaries such as reflectors, projectors and the like. To the practicing engineer, however, it is not so important, as in almost every case lamps should be used with reflectors, hence the distribution curve of the combination of lamp and reflector is the essential on which to base his design of an installation.

In general, lamp filaments are not formed to give particular distribution of light, as this can be so much more readily secured by the aid of reflecting devices. The variation in filament shape is necessary, however, to meet some special conditions which may arise in manufacture, or, as is the case with the focus type lamp, a desire to approximate a point source.

In Fig. 9 are shown a number of curves drawn to an arbitrary scale with views of the type of filament which gives the distribution.

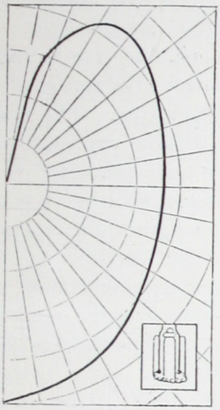
Inspection of these curves shows that since such a variation in shape results, the basis of rating lamps on mean horizontal candle-power is not comprehensive, and comparisons should be made on the basis of total light delivered, either in lumens or in mean spherical candle-power.



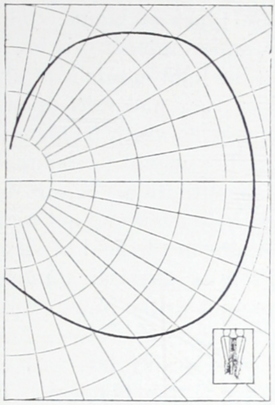
A—Low Wattage MAZDA B

B—High Wattage MAZDA C (loop construction)

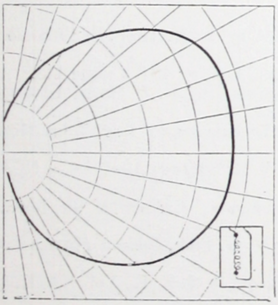
FIG. 9
Typical Vertical Light Distribution Curves of Various Shapes of MAZDA Lamp Filaments



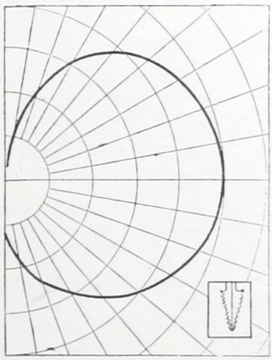
C—Low Wattage Mazda C (ring construction)



D—Concentrated, Stereopticon and Headlight Mazda C



E—Low Candle-power Street Series Mazda C Single Coil



F—High Candle-power Street Series, Mazda C Loop

Fig. 9 (*Con.*)

Effect of Frequency on Incandescent Lamps

Frequency of alternation will cause noticeable flicker with certain types of lamps. This flicker is less noticeable when the illumination intensity is low. The eye is most sensitive to flicker when the light enters it at about 45 degrees from the center of the field of view and falls upon the edge of the retina. The lowest frequency at which lamps may be operated without causing undue annoyance cannot be definitely stated as the personal factor enters into the situation. A certain amount of flicker may be annoying to one individual and not to another. The background and general conditions in the field of view also have an effect on this.

From a physical standpoint flicker is appreciably less with lamps such as the MAZDA having a positive temperature coefficient than for the carbon lamp having a negative coefficient. Flicker is also considerably less with a thick filament of a given material than for a thin filament. This is, of course, due to the greater heat of the former which prevents cooling between cycles and consequent diminution of light output.

Experience indicates that light from 25 cycle circuits is satisfactory for most purposes and yet for certain classes of service, low wattage lamps on 25 cycle circuits produce annoying flicker.

Frequency has no effect on the life of the lamp.

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